EXHIBIT M

STIGMATIZED ASSET VALUE: IS IT TEMPORARY OR LONG-TERM?

Jill J. McCluskey and Gordon C. Rausser*

Abstract—Stigma is a negative attribute of real estate acquired by environmental contamination and reflected in its value (Elliot-Jones, 1996). Using a model of neighborhood turnover with external economies, we show that both temporary stigma and long-term stigma are possible equilibrium outcomes after the discovery and cleanup of a hazardous waste site. The existence and duration of stigma are examined using hedonic price techniques with data from housing sales prices in Dallas County, Texas. We find that results depend critically on distance from the hazardous waste site. Neighborhood turnover due to changes in the level of poverty also appears likely.

I. Introduction

IN the past three decades, the public has become increasingly aware of environmental risks. This awareness is reflected in the negative impact of environmental contamination on property values. Stigma is a loss in property value beyond the cleanup cost of the contamination (Patchin, 1991). There are two externality effects that cause stigma. The first is an environmental externality on the properties adjacent to a hazardous waste site: the contamination causes neighboring property owners to be concerned about health issues. The second is a neighborhood externality: the association with a hazardous waste site can affect the composition of residents in the neighborhood and other attributes that determine neighborhood quality and property values. If the neighborhood externality is the source of the stigma, then remediating the hazardous waste site may not result in increased property values. Although some analysts have argued that uncertainty, or concern over whether the property is still contaminated, is a cause of stigma (Mundy, 1992), the neighborhood externality effect has not been considered.

When a triggering event results in direct damage, there may be a spillover or multiplier effect. The resulting additional damage is called consequential damage. In the case of a hazardous waste site, the environmental externality causes changes in the composition of a neighborhood, which, in turn, results in property value diminution above and beyond the immediate damage. Once environmental contamination becomes associated with a particular neighborhood, its property values may be stigmatized. Even if a potential homebuyer believes that the formerly contaminated area has been cleaned up, he or she will probably demand a discount. The resale value will most likely be lower than that of a comparable property without a history of contamination, if there is a market for the property at all. This reluctance to buy can be reflected in lower residential property values and may be based on perceived risk that may or may not have a scientific foundation.

A neighborhood may be distinguished as undesirable if it is identified as contaminated. Real estate has an intangible component that is determined by the public's perception of the location, similar to the intangible asset of goodwill on a corporation's balance sheet. When the public perceives that a neighborhood is no longer fashionable, the value of the intangible component falls. By making the neighborhood less desirable, a hazardous waste site decreases the value of the neighborhood's property, making it more affordable to lower-income families and less attractive to higher-income families. Over time, higher-income residents may relocate. As a result, the by-products of high-income residents, such as social status, good schools, low crime rates, quick police response, and well-maintained, owner-occupied homes, may disappear. Therefore, although the environmental problems are temporary, they affect the character of a neighborhood, creating long-term stigma.[1] In the worst-case scenario, outside businesses may "redline" the area, causing neighborhood businesses to relocate. In such a scenario, it is unlikely property values will rebound.[2]

Previous studies have attempted to measure benefits from the cleanup of hazardous waste by showing that residential property values decline as the distance to a hazardous waste site decreases (for example, Ketkar, 1992; Thayer, Albers, & Rahmatian, 1992). Extending this argument, if the hazardous waste site is remediated, then the discount for a location that is close to a former hazardous waste site should be recouped. A significant benefit of cleanup is then the difference between what property values were before the hazardous waste site and what they are with the hazardous waste site. However, if the neighborhood externality effect is the source of the stigma, then this reasoning is faulty. Consequently, if stigma effects from a site exist, then past studies that have made this value-recoupment argument may have overestimated the property-value benefits of cleanup of hazardous waste sites.

Received for publication June 28, 1999. Revision accepted for publication January 7, 2002.

* Washington State University and University of California, Berkeley, respectively.

This paper has benefited from discussions with Michael Hanemann, Zhihua Shen, Greg Adams, Larry Dale, Ken Rosen, Larry Karp, Ilya Segal, Robert Edelstein, David Zilberman, John Harris, Ron Mittelhammer, and Phil Wandschneider. Any remaining errors are the responsibility of the authors. This work was supported by an EPA–NSF grant. Jill McCluskey gratefully acknowledges financial support she received from the Fisher Center for Real Estate and Urban Economics at the U.C. Berkeley's Haas School of Business.

[1] Hall (1994) provides a case study of the effect of contamination on the value of an apartment property. An underground oil spill created unhealthy conditions, which led to a number of tenants leaving. Rents then declined, and the property became "seedy." Even after the spill was cleaned up, the property had substantially declined in value.

[2] Most changes to a neighborhood are reversible. It is usually possible for gentrification to take place. There is usually some reason for gentrification to occur, such as an amenity, an attractive location, or a desirable employer or business moving into the area. Bond (2001) found that formerly contaminated water-view lots in Australia fared better with respect to property diminution than lots without water views.

The Review of Economics and Statistics, May 2003, 85(2): 276–285

There are two major sources of uncertainty that arise from environmental contamination: (1) whether the property is still a health risk even after the property has been remediated and (2) what future potential liabilities exist and who is responsible for them. Using an expected-utility approach, it can be shown that the uncertainty surrounding hazardous waste sites can result in lower property values (Boyd, Harrington, and Macauley, 1996). More generally, a monetary value can be placed on irreversible events such as a permanent change in health status and loss of life, based on the choices an individual makes about income, consumption, and risk. A potential buyer must be compensated for the expected value of future damage to his health and an amount equal to a certainty equivalent to compensate for the risk associated with the contaminated site.

Uncertainty can also make it difficult for prospective buyers to obtain financing. Due to uncertainty about the risks of mortgaging contaminated properties, lenders' willingness to provide financing on contaminated properties fell from the late 1960s to a low point in the early 1980s, where it stayed until the early 1990s, when it began to improve.[3] During the low-willingness-to-finance period, the vast majority of lenders would not consider providing financing until the property has been remediated and satisfied certain tolerance limits. The result of the loss of mortgagability is often that the property is held off the market.[4] However, a recent increase in the understanding of the management of the risk surrounding contaminated properties has led to a greater willingness to provide financing for these properties.[5]

In this paper, we use a theoretical model with externality effects to show that both temporary stigma and long-term stigma are possible equilibrium outcomes after the discovery and cleanup of a hazardous waste site. The former is driven only by the environmental externality, whereas the latter is driven by the neighborhood externality. The existence and duration of stigma are then tested for by estimating a hedonic price model with data from housing sales prices in Dallas County, Texas. In the second stage of the hedonic price analysis, the bid functions are estimated to evaluate the externality characteristics of the model. The focus of the empirical analysis is the RSR lead smelter in West Dallas, which operated from 1934 to 1984 and caused soil contamination from air emissions and slag material. The pooled data set used in this analysis covers the period 1979 to 1995 and includes over 200,000 observations.

II. Previous Empirical Evidence

Many authors have used property transaction data to value environmental attributes and, more specifically, study the impact of hazardous waste sites. Researchers, such as Ketkar (1992), Kiel (1995), Kiel and McClain (1996), Kohlhase (1991), Smith and Desvousges (1986), and Thayer et al. (1992) have consistently found that proximity to hazardous waste sites and other locally undesirable land uses has a negative impact on property values.[6]

The current body of literature on the empirical effects of locally undesirable land uses does not address whether the diminution of property values caused by these land uses is temporary or long-term or whether externality effects exist. Although there have been many previous studies that attempt to measure the effect of environmental contamination and cleanup on property values, they generally focus on the short run. Most importantly, almost no studies have analyzed postcleanup property values. Typically, impacts of contamination on property values are examined with a cross-sectional data set at a single point in time.[7] Without including postcleanup property values, studies cannot structure the event analysis correctly to analyze the effects of cleanup. In contrast, this analysis examines the impact of environmental contamination on residential property values by analyzing data from before identification of the hazardous waste site; before, during, and after cleanup has been completed; and after new concerns were raised in the postcleanup years. Consequently, it is possible to consider the longer-run effects of contamination and remediation processes.

The exceptions to the lack of postcleanup analysis in the literature are Kohlhase (1991) and Dale et al. (1999). Kohlhase (1991) includes a toxic site in her study that was "almost cleaned up" at the time and finds statistically insignificant coefficient on price and distance. Dale et al. (1999) analyze the effect of the RSR smelter but take a different approach than is taken in the current analysis. They do not provide a theoretical foundation or a corresponding empirical analysis for distinguishing between long-term and temporary stigma. Moreover, they quantify the discontinuity of the distance price gradient surrounding the smelter by including indicator variables for two specific neighborhoods. As a result, they conclude that there was no long-term stigma associated with the RSR smelter. We approach this problem with a linear spline function, which specifically allows for the influence of the smelter to diminish with increasing distance, and arrive at different conclusions.

[3] This lack of mortgagability has been discussed in the appraisal and legal literatures. Patchin (1991, p. 169) writes, "This reluctance to lend applies not only to Superfund sites, but to sites with comparatively low levels of contamination." Lewandrowski (1994) discusses that in cases where financing is still available, interest rates will be higher.

[4] Patchin (1991, p. 169).

[5] A specialty of appraisal for contaminated properties was developed during the 1990s. During that time, the credit market went through a period of learning.

[6] For additional cites and a comprehensive survey of empirical results, see Farber (1998).

[7] Exceptions include Dale et al. (1999), Kohlhase (1991), and Kiel (1995), who examine property values at more than one point in time. Kiel and McClain (1996) examine housing prices before and after a failed incinerator siting.

III. Multiple-Equilibrium Hedonic Model

Sometimes property values recover following environmental contamination, and sometimes they do not. In the former instance, the environmental externality results in only a temporary stigma. Accordingly, our theoretical model allows for environmental contamination to lead to either a recovery equilibrium or long-term stigma on property values in formerly contaminated neighborhoods.[8]

Much of the current literature focuses only on uncertainty of health risk and liability as a potential cause of stigma (Mundy, 1992). If uncertainty is the only cause of stigma, then once the uncertainty is removed, values should recover. However, in the residential succession literature, externality models have been developed that emphasize the role of income levels or racial composition in explaining neighborhood turnover (Miyao, 1978; Coulson and Bond, 1990). If low-income residents enter a high-income neighborhood, then the composition of the neighborhood may *tip* from high income to low income. Such a neighborhood transformation could well result in long-term, rather than temporary, stigma.

The price of housing and land reflects consumers' valuations of all the attributes that are associated with housing, including environmental quality. The level of environmental contamination is a quality attribute of a differentiated product. Consumers can choose the level of environmental quality through their choice of a particular residential location. Housing prices may include premiums for locations in areas with high environmental quality. If so, the price differentials may be viewed as implicit prices for different levels of environmental quality. Given these issues, measuring these differentials requires a neighborhood turnover model with externalities (Coulson and Bond, 1990).

In the model specification, there are two types of households: high-income (Y_h) and low-income (Y_l), with $Y_h > Y_l$. Households consume one unit of housing and bid for housing in competitive rental markets.[9] Household preferences are represented by a strictly quasi-concave utility function that is increasing in the quality of housing, Q, provided by the unit rented, and the quantity of all other goods, X. The quality of housing is a function of the perceived environmental damage (E) and of the average income of the neighborhood in which the house is located ($\bar{Y}$), which introduces the neighborhood externality. The level of environmental damage plays the role of filtering that the age of housing stock represents in Coulson and Bond's (1990) model. Both types of households have the same preferences; the only difference is income. Both types would like to live in a neighborhood with a large proportion of high-income people.

In the proposed model, utility is generated by

$$U = U(Q(E, \bar{Y}), X), \tag{1}$$

where $Q_{\bar{Y}} > 0$ and $Q_E < 0$. Income goes toward rent and all other goods. Following Rosen (1974), preferences for residential quality can be expressed by bids for various qualities of housing, θ, that result in the same amount of utility. Assuming that there is no borrowing or lending, a household's budget constraint is then $X + \theta = Y$. Substituting the budget constraint in equation (1) and inverting allows the bid function to be derived:

$$\theta = \theta(E, \bar{Y}, U, Y). \tag{2}$$

It is assumed that housing quality is a normal good in equation (2); thus $\theta_{EY} < 0$.

Assuming an open city, each household has a utility level U_i^* ($i = l, h$) that is the default utility that is obtainable if that household locates outside the city. The neighborhood rental price for housing in equilibrium is

$$P(E, \bar{Y}, U_l^*, U_h^*, Y_l, Y_h) = \max_i \theta^i(E, \bar{Y}). \tag{3}$$

Housing will turn over from one income group to the other at the environmental damage level D at which

$$\theta^l(D, \bar{Y}, U_l^*) = \theta^h(D, \bar{Y}, U_h^*). \tag{4}$$

From $\theta_{EY} < 0$, it follows that $\theta_E^l > \theta_E^h$ at D. This means that high-income households place a higher value on housing with less environmental damage than D for a given $\bar{Y}$.

Mean neighborhood income will depend on the exogenous distribution of environmental contamination in the vicinity of the housing stock, $F(E) = \int_0^E f(u)\, du$. Assuming that the bid functions of low-income households are sufficiently high so that all housing is occupied, the mean neighborhood income is

$$\bar{Y} = F(E)Y_l + [1 - F(E)]Y_h. \tag{5}$$

The neighborhood equilibrium occurs at the values of $\bar{Y}$ and E that solve equations (4) and (5). The possibility of multiple equilibria in a similar model with filtering by age of the house is discussed in Coulson and Bond (1990). The requirement for uniqueness of the equilibrium condition is that

$$\theta_E^h - \theta_E^l + (\theta_{\bar{Y}}^h - \theta_{\bar{Y}}^l)(Y_h - Y_l)f(E) < 0. \tag{6}$$

The interpretation is that for the equilibrium to be unique the external effects of neighborhood average income must be sufficiently small relative to the effects of the environmental damage. If the initial income level of the neighborhood is equivalent to the post-environmental-damage income level, the stigma will only be temporary. However, if the initial income was high and the post-environmental-damage income is low, then a long-term stigma equilibrium results.

[8] There is also a third, unstable equilibrium.

[9] In the case of owner-occupied housing, the rental can be thought of as implicit.

The model can be easily generalized to include a continuum of income types. Following the standard hedonic price model, the price of housing, P, in Dallas County, Texas, is assumed to be described by a hedonic price function $P = P(z)$, where z is a vector of structural, neighborhood, and environmental attributes. The hedonic price of an additional unit of a particular attribute is determined as the partial derivative of the hedonic price function with respect to that particular attribute. Each consumer chooses an optimal bundle of housing attributes and all other goods in order to maximize utility subject to a budget constraint. The chosen bundle will place the consumer so that his indifference curve is tangent to the price gradient P_z. Therefore, the marginal willingness to pay for a change in a housing attribute is then equal to the derivative of the hedonic price function with respect to that attribute.

IV. Empirical Study of a Stigma Equilibrium

The model indicates that if the externality effect of average neighborhood income is strong enough, then it is possible for long-run stigma to result when environmental damage has occurred. The empirical study includes an analysis of which equilibrium emerged for the residential housing market near the RSR hazardous waste site in Dallas, Texas. Further, household bid functions are estimated in order to determine whether the neighborhood externality model is consistent with market behavior.

A. The Data Set

The data set includes 205,397 observations[10] with variables describing price and attributes of all single-family, detached homes sold over the period 1979 to 1995 in Dallas County, Texas (Dallas County Appraisal District). Each observation includes information (table 1) about the sale price[11] of the homes and different variables that affect the sale price, including house, neighborhood, and environmental quality attributes. As usual, housing quality is described by the square footage of living space, number of bathrooms, lot size, and indicator variables indicating the presence of a pool, central air conditioning, house condition, and similar variables. Neighborhood quality is based upon variables such as the percentage of households below the poverty level, school district, ethnic composition, and accessibility to the Dallas–Ft. Worth airport, the Dallas central business district (CBD), and the Galleria Mall. Environmental quality is described by proximity to the RSR lead smelter. Using a Geographic Information Systems (GIS) database, Dallas County is set up as a grid of X and Y coordinates. Coordinates are assigned to each house, the airport, the CBD, the Galleria Mall, and the RSR hazardous waste site. Distance can then be calculated between any two points. The GIS database is also used to link each house to its census tract (and the corresponding demographic information[12]) and its school district.

TABLE 1.—VARIABLE DEFINITIONS AND DESCRIPTIVE STATISTICS

Variable	Description	Mean	Std. Dev.
Price	Sales price of the home	104921	98168
Dprice	Deflated sales price of the home	86010	78940
Landarea	Lot size in square feet	9301.87	3969.60
Livarea	Living area in square feet	1797.43	755
Dalcbd	Miles to the Dallas central business district	10.90	3.92
Dfwair	Miles to Dallas–Fort Worth Airport	17.97	6.15
Galleria	Miles to the Galleria shopping center	10.89	5.76
Distrsr	Miles to the RSR facility	11.73	4.22
Age	Age of the house in years	19.97	16.18
Pool	1 if pool, 0 otherwise	0.14	0.34
Garg	1 if attached garage, 0 otherwise	0.87	0.33
Baths	Number of bathrooms	2.03	0.74
Pblack	% of the census tract that are African-American	11.05	16.98
Phisp	% of the census tract that are Hispanic	11.55	13.05
Pbpov	% of the census tract below the poverty line	7.68	7.20
Heatc	1 if central heating, 0 otherwise	0.88	0.32
Aircon	1 if central air conditioning, 0 otherwise	0.87	0.33
Good	1 if good condition, 0 otherwise	0.30	0.46
Average	1 if average condition, 0 otherwise	0.68	0.47
	School Districts		
CF	1 if Carrollton/Farmers Branch, 0 otherwise	0.07	0.26
Dallas	1 if Dallas school district, 0 otherwise	0.32	0.47
Cedar Hill	1 if Cedar Hill, 0 otherwise	0.01	0.11
Garland	1 if Garland, 0 otherwise	0.14	0.35
HP	1 if Highland Park, 0 otherwise	0.03	.015
Irving	1 if Irving, 0 otherwise	0.06	0.23
LWH	1 if Lancaster/Wilmer Hutchins, 0 otherwise	0.01	0.11
No district	1 if no district, 0 otherwise	0.07	0.26
MS	1 if Mesquite/Sunnyvale, 0 otherwise	0.05	0.02
Coppell	1 if Coppell, 0 otherwise	0.02	0.15
GP	1 if Grand Prairie, 0 otherwise	0.04	0.19
Richardson	1 if Richardson, 0 otherwise	0.13	0.34
Desoto	1 if Desoto, 0 otherwise	0.02	0.15
Duncan	1 if Duncanville, 0 otherwise	0.03	0.18

[10] As part of our data protocols, we exclude observations that seem unreasonable. The unreasonable observations are those with any of the following characteristics: price less than $4,000, lot size greater than 43,560 square feet or less than 400 square feet, and living area less than 400 square feet. This differs from Dale et al.'s (1999) data protocols, which delete observations with a selling price of less than $10,000 and a price per square foot of less than $40.

[11] Prices are deflated using the shelter housing price index (1982–1984 = 100) from the *Economic Report of the President*.

[12] For the non-Census years (1979, 1981–1989, 1991–1995), weighted averages are used, where the weights are based on the trend from 1980 to 1990.

The RSR lead smelter is located in the middle of Dallas County, approximately six miles west of the CBD. The smelter operated from 1934 to 1984 and was purchased in 1971 by the RSR Corporation. The smelter emitted airborne lead, which contaminated the soil in the surrounding areas. Lead debris created by the smelter was used in the yards and driveways of some West Dallas residences. In 1981, the U.S. Environmental Protection Agency (EPA) found health risks, and RSR agreed to remove any contaminated soil in the neighborhoods surrounding the RSR site using standards that were considered protective of human health at the time. In 1983 and 1984, additional controls were imposed by the City of Dallas and the State of Texas. In 1984, the smelter was sold to the Murmur Corporation, which closed it down permanently. In 1986, a court ruled that the cleanup was complete.

In 1991, the Center for Disease Control (CDC) lowered the blood level of concern for children from 30 to 10 micrograms of lead per deciliter of blood. Low-level lead exposure during childhood may cause reductions in intellectual capacity and attention span, reading and learning disabilities, hyperactivity, impaired growth, or hearing loss (Kraft and Scheberle, 1995). Also in 1991, the State of Texas found hazardous waste violations at the smelter. In 1993, the RSR smelter was placed on the Superfund National Priorities List (NPL).

Although initially high, the percentage of minority residents in close proximity to the smelter grew during the period of study. Within one mile of the RSR site, during 1979–1980, the mean percentage of Hispanic residents in the Census tracts where houses were sold was 54.8%. During 1991–1994, within one mile of the RSR site, this mean percentage of Hispanic residents in the Census tracts where houses were sold increases to 69.2%. The comparable percentages for Dallas County as a whole are 8.8% and 13.8%, respectively.

B. *Event Analysis*

The analysis covers the impact of the smelter on property values over four event-driven time periods: (1) pre-1981, when the smelter operated but health risks were not officially identified or publicized; (2) 1981–1986, when health risks from soil contamination were officially identified, cleanup was initiated, and a court ruled cleanup was completed; (3) 1987–1990, after cleanup was again ruled complete; and (4) 1991–1995, when new concerns arose and additional cleanup occurred. The event analysis allows us to analyze which of the equilibria occurred. Slovic et al. (1991) provide support for the use of event-driven time periods. They write, "Social amplification [of risk] is triggered by the occurrence of an adverse event."[13] Kiel and McClain (1995) also divide their data into event-driven time periods in order to analyze the effect of changes in information over time about an incinerator siting on property values.

In addition to considering division by event-driven time periods, Chow tests are performed to evaluate whether structural changes occurred. The results indicate that every year, with one exception, is significantly different from the previous one. The exception is that the data from sales in 1993 are not significantly different from those from sales in 1994. In addition, Wald tests for structural change, which do not assume that the disturbance variance is the same across regressions, are performed to test if the event-driven periods are the same. The results indicate that each period is significantly different from the others. In order to partially control for the differences across years within the event-driven time periods, indicator variables are included to the indicate year of sale.

In addition to the statistical measures, there are obvious differences across the event-driven time periods. Before the identification of the smelter as a hazardous waste site, houses were sold as close as 0.17 miles to it. In the first period after cleanup (1987–1990), no houses within a mile of the RSR site were sold.[14] These results can be interpreted to mean that home sellers and buyers have different expectations during each of our time periods. During the first postcleanup period (1987–1990), it is possible to look at postcleanup stigma. After 1991, when the new concerns arise, there should be different expectations.

C. *Estimation Techniques and Functional Form*

Rosen (1974), who proposes a two-step process, develops the hedonic model. The first step is to estimate the hedonic price function. In the second step, the hedonic prices of the attributes are used as dependent variables in the estimation of (inverse) bid functions. In order to solve the identification problem and achieve consistent estimation of the two-step model, it is assumed that supplies of housing attributes are exogenously given and vary across submarkets, and household demand is a function of observable household characteristics and a single unobserved taste variable (Coulson and Bond, 1990). This taste variable has the same conditional distribution across submarkets. These assumptions are standard in hedonic demand studies and can be defended to the extent that most of the housing stock is accumulated capital in place, and adjustment costs are high. Consequently, the current state of an area's housing market is largely determined by the accumulated effects of historical accidents in that market. This means that the marginal implicit prices of attributes will vary independently of the other demand-shift variables (Coulson and Bond, 1990). Under this specification, ordinary least squares can be used to estimate the hedonic price equation, but not the bid functions, because

[13] Slovic et al. (1991, p. 685).

[14] The usual explanation for a lack of sales around a locally undesirable land use is that there are no buyers. However, it may also be the case that potential sellers are holding on to their properties with the hope that property values will rise.

their error term is influenced by the unobserved taste component. An instrumental variables approach can be used in the second step if the conditions for identification are met.

Our study follows the previously cited literature on the empirical effects of locally undesirable land and considers only linear and semilog (natural logarithm of the dependent variable) functional forms. A linear specification has the obvious interpretation that a unit increase in an attribute causes the price to rise by an amount equal to the coefficient; with a semi-log specification, the coefficients can be interpreted as percentages of the average house price. Given the presence of independent indicator variables, a Box-Cox transformation of the dependent variable is used to choose between the linear or natural logarithmic forms for the dependent variable. The hypothesis that the linear form is preferred could be rejected for every year. Although the hypothesis that the semi-log specification is best could be rejected for most years, the estimates of λ are always close to zero.[15] Given this limited analysis of functional form, the following semi-log specification below is reported:

$$\ln P(x) = \beta_0 + \sum \beta_i x_i + \varepsilon, \qquad (7)$$

where P is the sale price of the home, the x_i's are the various attributes of the house, and ε is a white-noise error term.

D. *Quantitative Measures of Distance Stigma*

We first estimate the standard distance model given by equation (7) for the entire Dallas County housing market. The estimation results are presented in table 2. The estimated coefficients have the expected signs and are statistically significant in each period, with only a few exceptions. These exceptions are that a few of the school-district indicator variables are not significant at conventional levels in the first and third time periods. In addition, a few of the school-district indicator coefficients vary significantly over time. This can be explained by the fact that there are different information sets for each time period for the tradeoffs between the value of location in a specific school district and health risks. Additional baths, living area, and lot size increase the sale price of a home. Also, the presence of a pool, garage, central air conditioning, and central heat each have a positive effect on home values. Houses in good or average condition command a price premium. Houses that are located in census tracts with higher percentages of poverty, African-American residents, and Hispanic residents, sell at lower prices. Houses that are close to the Galleria Mall sell at higher prices than those that are farther away in all four periods. The signs on the coefficients of the distance variables (distance to the airport, the RSR smelter, and the central business district) change over time in this model.

Our first hypothesis is that people pay a premium for distance from the RSR smelter. The price gradient for distance starts out significantly positive before the EPA identification of the RSR site and during cleanup of the site, indicating that buyers are willing to pay a premium for a location that is farther away from the RSR site. The positive sign on distance before EPA identification can be interpreted to mean that some effect of the RSR site was already capitalized in property values in 1979–1980. However, after cleanup, this coefficient turns significantly negative. This differs from the expected sign of the distance coefficient, which is either positive or zero.

TABLE 2.—DISTANCE MODEL HEDONIC ESTIMATION RESULTS*

	Value			
Variable	1979–1980	1981–1986	1987–1990	1991–1995
Livarea	4.39E−4 (96.31)	4.31E−4 (179.54)	4.21E−4 (157.64)	4.08E−4 (156.19)
Baths	0.090 (21.58)	0.064 (27.78)	0.057 (21.90)	0.064 (23.88)
Pool	0.050 (8.53)	0.079 (26.77)	0.098 (30.17)	0.072 (20.71)
Landarea	9.50E−7 (1.88)	2.90E−6 (11.27)	4.45E−6 (15.01)	6.64E−6 (22.75)
Garage	0.087 (20.37)	0.090 (33.92)	0.093 (25.66)	0.138 (39.51)
Aircon	0.107 (15.42)	0.125 (28.30)	0.135 (21.81)	0.200 (32.63)
Heatc	0.110 (15.41)	0.085 (18.50)	0.101 (15.70)	0.164 (27.08)
Good	0.218 (15.97)	0.293 (35.38)	0.452 (43.88)	0.642 (79.78)
Average	0.150 (11.75)	0.164 (20.46)	0.284 (28.07)	0.426 (54.32)
Galleria	−0.019 (−13.16)	−0.014 (−21.73)	−0.014 (−19.54)	−0.021 (−30.45)
Dalcbd	−0.016 (−5.59)	−0.032 (−21.44)	0.004 (2.05)	0.016 (8.76)
Dfwair	−0.007 (−3.42)	−0.014 (−14.30)	0.002 (1.78)	0.007 (6.16)
Pbpov	−0.008 (−15.26)	−0.003 (−10.55)	−0.002 (−5.61)	−0.003 (−13.49)
Pblack	−0.002 (−14.81)	−0.003 (−36.40)	−0.005 (−44.04)	−0.007 (−73.45)
Phisp	−0.003 (−11.23)	−0.004 (−29.15)	−0.007 (−42.06)	−0.007 (−50.62)
Distrsr	0.011 (3.50)	0.018 (10.78)	−0.033 (−15.87)	−0.048 (−23.93)

* The coefficients for years and school districts are suppressed due to space limitations. Please contact the corresponding author to obtain these results. t-Statistics are in parentheses.

[15] The Box-Cox transformation is

$$p(\lambda) = \begin{cases} \dfrac{P^{\lambda} - 1}{\lambda}, & \lambda \neq 0, \\ \ln \lambda, & \lambda = 0. \end{cases}$$

Using Box-Cox maximum likelihood analysis, λ was estimated for each year. The yearly estimates of λ range from −0.09 to 0.21. A value of λ = 0 (λ = 1) implies that a semi-log (a linear) specification is best.

There are a number of explanations for the negative signs on distance in the postcleanup periods. The most compelling explanation is that sphere of influence of the smelter is limited. This issue is explored with an examination of the continuity price gradient for distance. Another possible explanation is that very few houses in close proximity to the smelter were sold after cleanup. These discounted houses no longer affect the coefficient on the distance variable after cleanup.[16]

Our second hypothesis is that the coefficient on distance did not change over the different event-driven time periods. This hypothesis is a crude test of the duration of stigma.[17] For example, if the coefficient on distance starts out positive, and then after remediation it is no longer positive, then stigma is only temporary. Although we already know that the coefficients change from significantly positive to significantly negative, F-tests have been conducted to test whether the distance coefficient in each period is equal to the coefficient on distance in every other period. All of these hypotheses can be rejected, which indicates that the coefficients on distance did significantly change across periods. The F-statistics range from 8.66 to 619.92.

Continuity of the Price Gradient: Previous studies, such as McClelland et al. (1983), find that the impact of the waste site on property values dissipates rapidly with distance. Following Thayer et al. (1992), we use linear spline functions to allow for discontinuities of the price gradient. Linear splines allow for there to be one premium for distance up to a critical point and then an adjustment to the premium after that point. We first allow the price gradient to be discontinuous at one point, and then attempt to choose the critical point from the set {1, 1.1, 1.2, 1.3, . . . , 10} using a grid search with the entire data set.[18] Our criterion for choosing the critical point is minimizing the sum of squared errors. There are two values that result in local minima, and a third value that results in a global minimum. From these findings, we allow the price gradient to be discontinuous at three points. Thayer et al. (1992) conclude from their findings that there is more than one shift in the hedonic function for their data, but they do not allow for additional shifts in the price gradient for distance. Using a second grid search, we choose the following three critical points: 1.2, 2.6, and 4.6 miles.

TABLE 3.—HEDONIC PRICE REGRESSIONS WITH LINEAR SPLINE FUNCTION

Period	Quantity	Value	t-Statistic	Price Gradient
1979–1980	Distance from RSR	0.880	4.88	0.880
	Adjustment 1 (1.2 miles)	−1.100	−5.68	−0.220
	Adjustment 2 (2.6 miles)	0.279	8.09	0.059
	Adjustment 3 (4.6 miles)	−0.048	−6.27	0.011
1981–1986	Distance from RSR	2.394	7.36	2.394
	Adjustment 1 (1.2 miles)	−2.553	−7.71	−0.159
	Adjustment 2 (2.6 miles)	0.209	10.97	0.050
	Adjustment 3 (4.6 miles)	−0.020	−4.19	0.030
1987–1990	Distance from RSR	0.936	1.52	0.936
	Adjustment 1 (1.2 miles)	−1.170	−1.87	−0.234
	Adjustment 2 (2.6 miles)	0.231	9.02	−0.003
	Adjustment 3 (4.6 miles)	0.011	1.69	0.008
1991–1995	Distance from RSR	3.223	7.21	3.223
	Adjustment 1 (1.2 miles)	−3.665	−8.04	−0.442
	Adjustment 2 (2.6 miles)	0.424	17.29	−0.018
	Adjustment 3 (4.6 miles)	0.020	3.41	0.002

Formally, the linear spline is structured as follows: Let x_1 be the distance to the site, let x_2, x_3, and x_4 be the distances at which the price gradient is allowed to be discontinuous, and let x_5 to x_n be the other attributes of the house. The linear spline can be represented as

$$\begin{aligned} \ln P(x) = \beta_0 + \beta_1 x_1 + \beta_2 d_2(x_1 - x_2) \\ + \beta_3 d_3(x_1 - x_3) + \beta_4 d_4(x_1 - x_4) \\ + \sum \beta_i x_i + \varepsilon, \end{aligned} \tag{8}$$

where

$$d_2 = \begin{cases} 1 & \text{if } x_1 > x_2, \\ 0 & \text{otherwise,} \end{cases}$$

$$d_3 = \begin{cases} 1 & \text{if } x_1 > x_3, \\ 0 & \text{otherwise,} \end{cases}$$

$$d_4 = \begin{cases} 1 & \text{if } x_1 > x_4, \\ 0 & \text{otherwise.} \end{cases}$$

The coefficient associated with each critical point becomes an adjustment term in the distance coefficient. The adjustments to the price gradient are cumulative:

$$\frac{d \ln P(x)}{dx_1} = \beta_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 d_4. \tag{9}$$

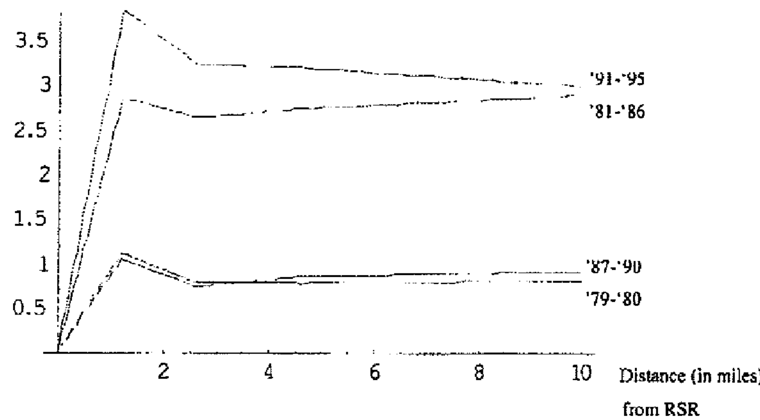
Hedonic Empirical Results: We estimate the hedonic model with linear splines given by equation (8). The estimation results are presented for the distance coefficient β_1 and the adjustment coefficients β_2, β_3, and β_4 in table 3 and are depicted graphically in figure 1. The hypothesis that the effect of the smelter is constant with distance can be rejected if the coefficients for the adjustment variables are different from zero. The coefficients on the adjustment variables are significantly different from zero for each critical point in

[16] Dale et al. (1999) offer two possible explanations for a negative distance coefficient in a previously stigmatized area. First, the econometric model may be misspecified. Second, the cleanup could have provided amenities not found elsewhere in the urban area. We agree that the simple distance model is misspecified because of the discontinuity in the price gradient. We did not find any evidence that the cleanup provided unique amenities.

[17] The reason that this is a crude test for the duration of stigma is that the price gradient for distance from the smelter will be discontinuous if the sphere of influence of the smelter dissipates rapidly with distance.

[18] One mile is the lowest possible starting point, because the number of sales transactions is very small in close proximity to the smelter.

FIGURE 1.—LOG OF PRICE PREMIUM FOR DISTANCE FROM THE RSR SMELTER



each period. As expected, in each period, the distance coefficient is positive, and the adjustment at 1.2 miles is negative. The interpretation is that the first adjustment coefficient is negative because the influence of the smelter diminishes with increasing distance. The second adjustment to the price gradient is positive in each case. This is caused by some higher-price houses that are close but outside the 1.2 mile sphere of influence of the smelter. The third adjustment is sometimes positive and sometimes negative but always small in relative magnitude.

The duration of stigma in close proximity to the smelter can be tested while allowing for discontinuities in the price gradient. We conduct F-tests to discern whether the distance coefficient in each period is equal to that in every other period. The distance coefficient for period 3 (1987–1990) is not significantly different from that for period 1 (1979–1980), and the distance coefficient for period 2 (1981–1986) is not significantly different from that for period 4 (1991–1994). The rest of these hypotheses can be rejected, which indicates that the effect of proximity to the smelter does significantly change for these periods. The F-statistics range from 4.81 to 23.23.

The positive coefficient on the distance coefficient in 1979–1980 should be interpreted to mean that the market was aware of the smelter as a disamenity. However, after EPA identification of the RSR site as a hazardous waste site, this coefficient significantly increases. The fact that the coefficient greatly increases in magnitude provides further support that a neighborhood externality occurred.

The finding that the price gradient for a distance of less than 1.2 miles is positive after remediation of the site and before the period of new concern is important. It means that, within the 1.2 mile radius of the RSR site, home buyers pay a premium for a home that is located farther away from the RSR site, even after a court ruled that the site was cleaned up. In other words, with the linear spline model, we find that there was a postcleanup stigma (1987–1990) within a very limited (no greater than 1.2 miles) sphere of influence. There is also evidence of stigma during the period 1991–1995, but the additional concerns and new information complicate this result.

E. Bid-Function Estimation

In order to estimate a two-step hedonic model with bid functions, we segment the Dallas County housing market into four submarkets by combining similar school districts in the same geographic area. The groupings with price statistics are presented in table 4. Segmenting the market solves the identification problem, because similar individuals must choose in markets with different hedonic price functions (Freeman, 1993). To implement this approach, we first estimate separate hedonic price functions for each housing submarket, using the same specification. Next, the

TABLE 4.—DALLAS COUNTY HOUSING SUBMARKETS

Submarket	School Districts	Mean (Std. Dev.) Real Sales Price	Mean (Std. Dev.) Hedonic Price for Distance	Mean (Std. Dev.) Hedonic Price for Poverty
Northeast	Garland, Richardson, Mesquite/ Sunnyvale, no district	84,142 (58,463)	−0.012 (0.0004)	−0.001 (7.45E−6)
Northwest	Carrollton/Farmers Branch, Coppell	85,720 (36,410)	2.148 (0.590)	0.038 (0.004)
South	Duncanville, Cedar Hill, Desoto, Lancaster/Wilmer Hutchins	67,069 (34,644)	1.570 (0.567)	−0.031 (0.004)
Central	Dallas School District, Highland Park, Irving, Grand Prairie	91,046 (106,515)	−0.183 (0.217)	−0.016 (0.003)

TABLE 5.—PARAMETER ESTIMATES OF INVERSE DEMAND FUNCTION FOR DISTANCE FROM RSR DEPENDENT VARIABLE

	Period 1 (1979–1980)	Period 2 (1981–1986)	Period 3 (1987–1990)	Period 4 (1991–1995)
Intercept	3.850 (27.35)	64.031 (2.17)	57.310 (15.19)	888.089 (292.69)
Distance from RSR	−3.847 (−31.14)	8.424 (3.02)	−48.077 (−15.06)	−750.377 (−291.56)
Adjustment 1 (starts at 1.2 miles)	4.345 (32.74)	−64.659 (−2.89)	48.371 (14.91)	755.669 (287.96)
Adjustment 2 (starts at 2.6 miles)	−0.558 (−23.53)	45.449 (1.71)	−0.176 (−1.28)	−2.909 (19.98)
Adjustment 3 (starts at 4.6 miles)	0.108 (22.07)	29.591 (3.98)	−0.065 (−2.02)	−2.369 (−69.67)
% Poverty	−0.004 (−12.53)	−9.657 (−27.57)	−0.031 (−22.14)	−0.006 (−4.73)
% Black	8.6E−04 (11.09)	1.229 (11.34)	−0.002 (−4.65)	8.17E−04 (1.84)
% Hispanic	0.004 (21.19)	3.427 (16.00)	0.009 (10.73)	0.010 (14.35)
Living area	2.28E−05 (12.40)	1.59E−03 (0.82)	−4.02E−05 (−5.11)	2.67E−06 (0.31)

t-Statistics in parentheses.

hedonic prices of the attributes are used as dependent variables in the estimation of (inverse) bid functions. Presuming that other goods are separable from housing attributes, the parameters of the bid functions can be estimated using housing characteristics and demographic variables that shift preferences as explanatory variables.

In this stage, we compute the prices of the attributes as the derivative of the hedonic price function with respect to the appropriate attribute. The attributes we focus on are the distance from the hazardous waste site and the percentage of poverty in the census tract in which the house is located. The independent variables in these attribute demand equations include attribute quantities for distance, percentage of poverty, living area, and the following census tract information to represent demographics: percentage of African Americans and percentage of Hispanics.[19] Since the attribute quantities are endogenous variables, two-stage least squares estimation is used. Variables that are uncorrelated with the error term but highly correlated with the endogenous variable are appropriate instruments. This means that variables that vary across sub-markets can be included as instruments. Therefore, following Bartik (1987) and Coulson and Bond (1990), we use cross products between demand characteristics and submarket indicator variables as instruments.

The regression for the price of distance from the RSR smelter site (see table 5) indicates that households from higher-income census tracts are willing to bid significantly more for houses that are located farther away from the smelter than are households from lower-income census tracts. This supports the filtering aspect of the model with respect to distance from the hazardous waste site.

The neighborhood turnover hypothesis from the theoretical model is reflected in the coefficients on the income-related variable (poverty) in the inverse demand functions. The positive and highly significant coefficients on poverty in the price (discount) for poverty in the census tract (see table 6) in all but the first postcleanup period (1987–1990) can be interpreted to mean that people from higher-income areas require a larger discount to live in a lower-income neighborhood. The estimation results for periods 1, 2, and 4 are consistent with the neighborhood externality aspect of our theoretical model and with Coulson and Bond's (1990) findings. The one sign that contradicts the model is in period 3, the period in which few sales occurred in close proximity to the RSR site. Therefore, we conclude that our empirical results support the hypothesis that the neighborhood externality effect is strong, and the stigma may be long-term within 1.2 miles of the RSR site.

TABLE 6.—PARAMETER ESTIMATES OF INVERSE DEMAND FUNCTION FOR PERCENTAGE OF POVERTY IN CENSUS TRACT DEPENDENT VARIABLE

	Period 1 (1979–1980)	Period 2 (1981–1986)	Period 3 (1987–1990)	Period 4 (1991–1995)
Intercept	−0.010 (−2.89)	0.002 (0.40)	−0.118 (−2.69)	0.058 (3.48)
Distance from RSR	−0.006 (−1.95)	−0.009 (−1.97)	0.093 (2.52)	−0.059 (−4.19)
Adjustment 1 (starts at 1.2 miles)	0.007 (2.27)	0.010 (2.13)	−0.100 (−2.67)	0.064 (4.47)
Adjustment 2 (starts at 2.6 miles)	−0.004 (−6.68)	−0.002 (−8.02)	0.015 (9.39)	−0.012 (−14.62)
Adjustment 3 (starts at 4.6 miles)	0.003 (27.10)	0.001 (19.74)	−0.007 (−19.25)	0.009 (48.90)
% Poverty	2.06E−04 (21.06)	2.13E−04 (36.11)	−0.002 (−90.46)	6.28E−04 (53.65)
% Black	7.43E−06 (3.77)	−9.59E−06 (−6.73)	5.45E−04 (80.25)	−1.88E−04 (−61.33)
% Hispanic	1.94E−05 (3.91)	−8.54E−05 (−32.34)	8.06E−04 (64.90)	−2.16E−04 (−41.11)
Living area	7.43E−07 (16.39)	−1.95E−08 (1.05)	−6.8E−07 (−7.45)	9.96E−07 (20.94)

t-Statistics in parentheses.

[19] Since individual demographic data for the homebuyer associated with each transaction are unavailable, census tract data are used as a proxy. The loss of detail from using census tract data is a drawback. However, Freeman (1993) points out that census tract boundaries are chosen in an effort to construct relatively homogeneous units in terms of housing and socioeconomic characteristics. If within-tract variation is small compared with the variation among tracts, then little is lost with the use of census tract data.

VIII. Conclusion

In this paper, we present a simple theoretical model with externalities to show that it is possible to arrive at either a long-term stigma equilibrium or a recovery equilibrium (temporary stigma) after the detection and cleanup of a hazardous waste site. If the recovery equilibrium is the one that emerges, there will only be a temporary drop in property values. In our empirical analysis, we use hedonic price functions to analyze whether a stigma equilibrium or a recovery equilibrium emerges for the residential properties and estimate bid functions for two attributes in order to find empirical support for the theoretical model.

Our empirical evidence shows that long-term stigma exists in a very limited area. The sphere of influence of the smelter is no larger than a circle around the smelter with a 1.2-mile radius. In the years directly following cleanup, properties within 1.2 miles of the RSR sell at significantly lower prices than properties located farther away. From our estimation of the bid functions in the second stage of our hedonic price analysis, we find evidence that supports the neighborhood externality model. Households from higher-income neighborhoods require a larger discount to live in close proximity to the remediated hazardous waste site and a larger discount to live in a low-income neighborhood.

REFERENCES

Bartik, Timothy J., "The Estimation of Demand Parameter in Hedonic Price Models," *Journal of Political Economy* 95 (February 1987), 81–88.

Bond, Sandra G., "Stigma Assessment: The Case of a Remediated Contaminated Site," *Journal of Property Investment and Finance* 19 (2001), 188–210.

Boyd, James, Winston Harrington, and Molly K. Macauley, "The Effects of Environmental Liability on Industrial Real Estate Development," *Journal of Real Estate Finance and Economics* 12 (January 1996), 37–58.

Coulson, N. Edward, and Eric W. Bond, "A Hedonic Approach to Residential Succession," this REVIEW, 72 (August 1990), 433–443.

Dale, Larry, James C. Murdoch, Mark A. Thayer, and Paul A. Waddell, "Do Property Values Rebound from Environmental Stigmas? Evidence from Dallas County, Texas," *Land Economics* 75 (1999), 311–326.

Elliot-Jones, Michael, "Stigma in Light of Recent Cases," *Natural Resources & Environment* (Spring 1996), 56–59.

Farber, Stephen, "Undesirable Facilities and Property Values: A Summary of Empirical Studies," *Ecological Economics* 24 (January 1998), 1–14.

Freeman, A. Myrick, *The Measurement of Environmental and Resource Values: Theory and Methods* (Washington: Resources for the Future, 1993).

Hall, Robert W., "The Causes of Loss in Value: A Case Study of a Contaminated Property," *Real Estate Issues* 19 (April 1994), 32–38.

Ketkar, Kusum, "Hazardous Waste Sites and Property Values in the State of New Jersey," *Applied Economics* 24 (June 1992), 647–659.

Kiel, Katherine A. "Measuring the Impact of the Discovery and Cleaning of Identified Hazardous Waste Sites on House Values," *Land Economics* 71 (November 1995), 428–435.

Kiel, Katherine A., and Katherine T. McClain, "House Prices during Siting Decision States: The Case of an Incinerator from Rumor through Operation," *Journal of Environmental Economics and Management* 28 (March 1995), 241–255.

——— "House Price Recovery and Stigma after a Failed Siting," *Applied Economics* 28 (November 1996), 1351–1358.

Kohlhase, Janet E., "The Impact of Hazardous Waste Sites on Housing Values," *Journal of Urban Economics* 30 (July 1991), 1–26.

Kraft, Michael E., and Denise Scheberle, "Environmental Justice and the Allocation of Risk: The Case of Lead and Public Health," *Policy Studies Journal* 23 (Spring 1995), 113–123.

Lewandrowski, Lorraine, "Toxic Backfire: Appraisal Techniques and Current Trends in Valuation," *Albany Law Journal of Science and Technology* (1994), 1–32.

McClelland, Gary H., William D. Schulze, and Brian Hurd, "The Effects of Risk Beliefs on Property Values: A Case Study of a Hazardous Waste Site," *Risk Analysis* 10 (December 1990), 485–497.

Miyao, Takahito, "Dynamic Instability in a Mixed City in the Presence of Neighborhood Externalities," *American Economic Review* 68 (June 1978), 454–463.

Mundy, Bill, "Stigma and Value," *The Appraisal Journal* (January 1992), 7–13.

Patchin, Peter J., "Contaminated Properties—Stigma Revisited," *The Appraisal Journal* (April 1991), 167–172.

Rosen, Sherwin, "Hedonic Prices and Implicit Markets," *Journal of Political Economy* 90 (January–February 1974), 34–55.

Slovic P., M. Layman, N. Kraus, J. Flynn, J. Chalmers, and G. Gesell, "Perceived Risk, Stigma, and Potential Economic Impacts of a High-level Nuclear Waste Repository in Nevada," *Risk Analysis* 11 (December 1991), 683–696.

Smith, V. Kerry, and William H. Desvousges, "The value of avoiding a LULU: Hazardous Waste Disposal Sites," *The Review of Economics and Statistics* 68 (May 1986), 293–299.

Thayer, Mark, Heidi Albers, and Morteza Rahmatian, 1992, "The Benefits of Reducing Exposure to Waste Disposal Sites: A Hedonic Housing Value Approach," *Journal of Real Estate Research* 7 (Summer 1992), 265–282.